Active Circuits
Lecture 1: Introduction To Active Filters

ELC 302 – Spring 2012

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Filters

- Early 1920s to Late 1960s: Voice filters were realized in RLC networks.
- In the 1950s: a goal to reduce the size and cost of inductors by replacing them by active circuits was launched.
- First book on Active RC Circuits “Theory and Design of Active RC Circuits,” Mc Graw-Hill co., NY 1968.
- Early 1970s, Thin-film hybrid integrated circuits were developed.

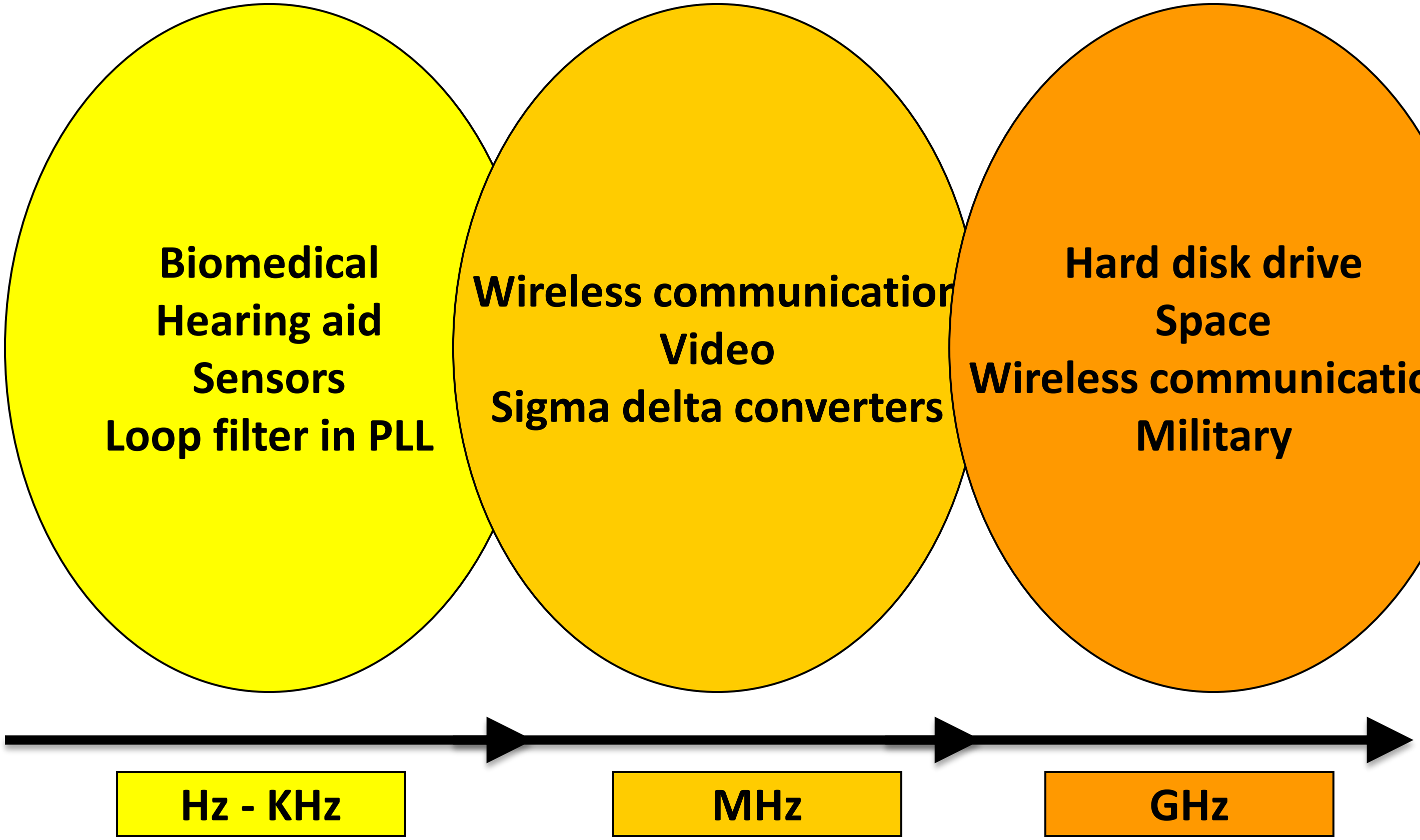
History

Filters

- Integrating filters on chip is one of the main demands in most systems.

- Active RC filters, G_m-C filters, Switched-Capacitor Filters are all types of filters that can be integrated on chip.

Filter Applications



Biomedical
Hearing aid
Sensors
Loop filter in PLL

Wireless communication
Video
Sigma delta converters

Hard disk drive
Space
Wireless communication
Military

Hz - KHz

MHz

GHz

Passive Filters - RLC

- Use Passive components (R, L, C)
- Do not provide gain (at DC)
- Bulky inductors for low frequencies (not suitable for integrated circuits)
- Filters parameters are coupled (changing one component can change different filter parameters)
- Cannot realize ideal integrator
- Suitable for high-Q filters (high selectivity)
- Typical 2nd order filter transfer function is given by:

$$H(s) = \frac{G_{DC}}{1 + \frac{s/\omega_0}{Q} + (s/\omega_0)^2}$$

Passive Filters - RC

- Filters constructed with Resistors and Capacitors only result only in real poles.
- Cannot Realize Q > 0.5 (Explain why!!)
- Selectivity is always poor.
- Bulky dimensions for low frequencies.

Active RC Filters

- Use of Rs and Cs along with active components (mainly opamps) to provide high-Q (high selectivity) filters.

- Effectively, inductors are replaced with Active Circuits. (A circuit that emulates the inductor functionality).

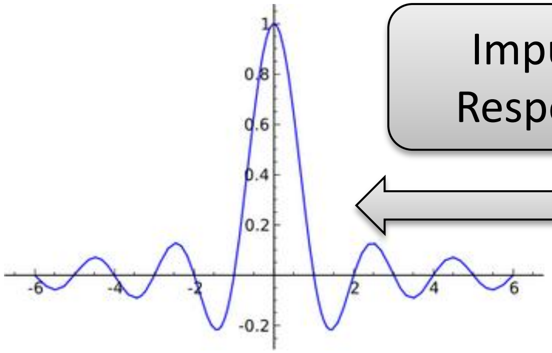
Types of Filters

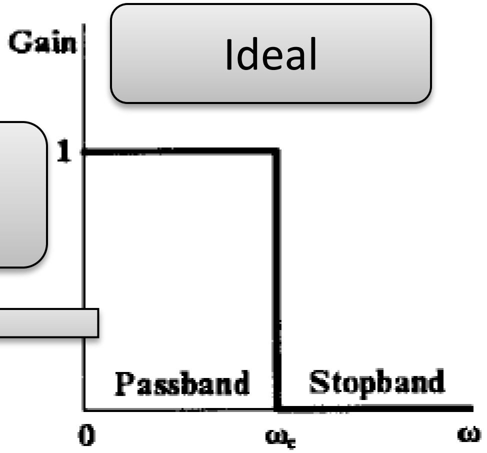
- Low Pass Filter (LPF):

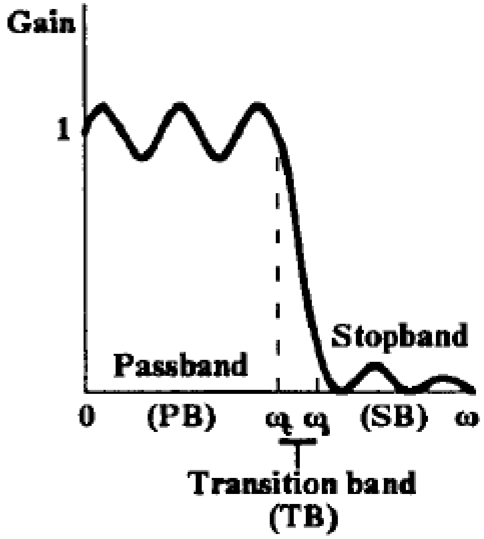
Practical - Approximation

Ideal

Impulse Response



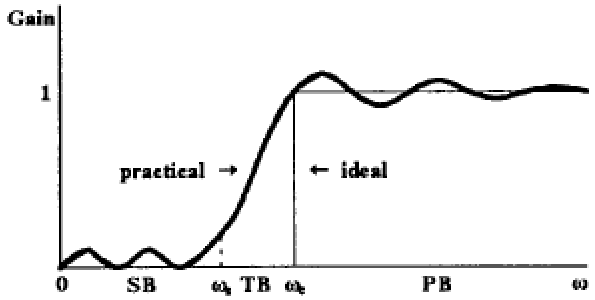




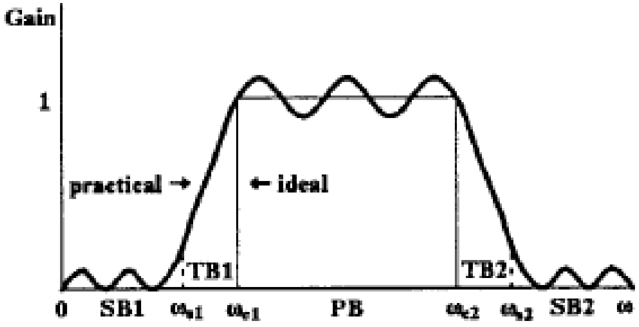
- Ideal response is called: “Brick Wall”
- Ideal response is not feasible because its impulse response has non-zero values for t<0 → Non-causal system

Types of Filters

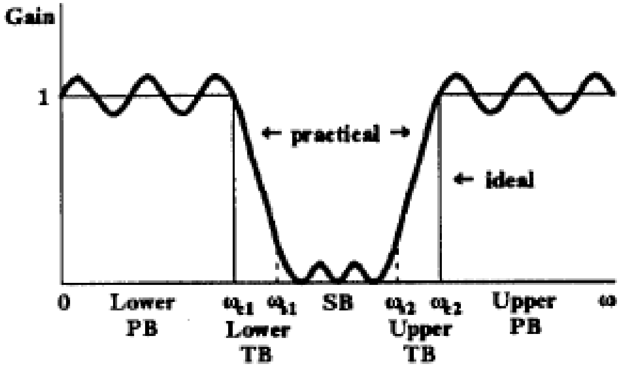
- High-Pass Filter (HPF):



- Band-Pass Filter (BPF):



- Band-Stop Filter (BSF):

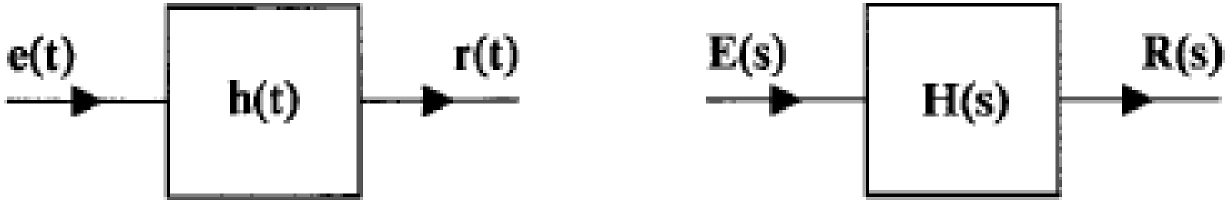


Types of Filters

- All-Pass Filter (APF):
  - All-pass filters do not change the magnitude of the input, rather they only change the phase.
  - Can be used in phase equalization.

- Amplitude Equalizers:
  - The amplitude equalizer has an amplitude response that does not belong to any of the filter responses considered above.
  - It is used to compensate for the distortion of the frequency spectrum that the signal suffers when passing through a system (cable, wire, optical fiber … etc).
  - Its amplitude response is therefore drawn as complementary to the signal spectrum.

Continuous-Time Filters

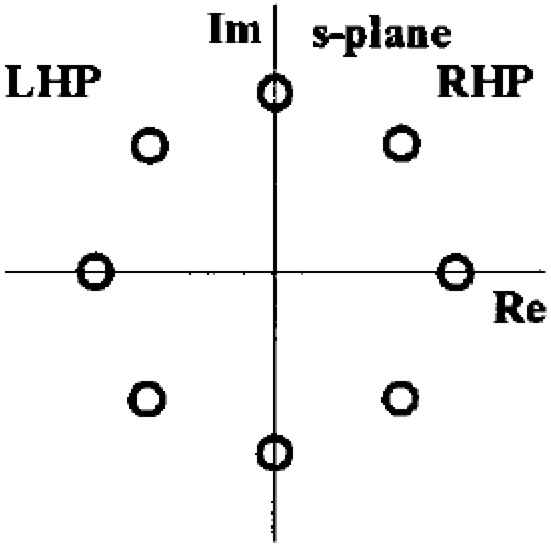


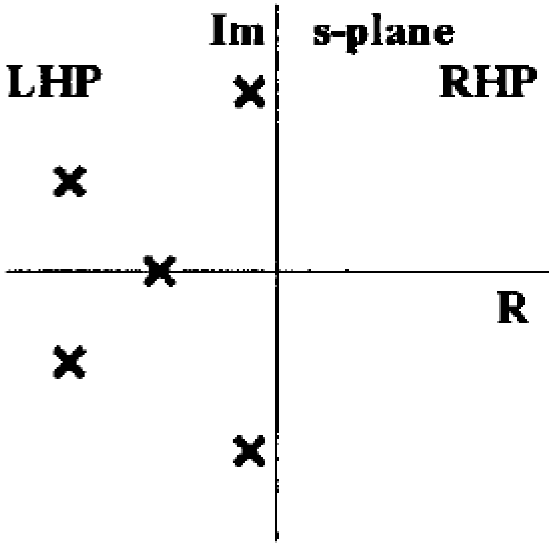
- In time domain:
  - $r(t) = \int_0^t h(t-\tau)e(\tau)d\tau$
- In frequency domain:
  - $R(s) = H(s)E(s)$
  - H(s) : Filter transfer function
- $H(s) = \frac{N(s)}{D(s)} = \frac{a_n s^n + a_{n-1}s^{n-1} + \cdots + a_1 s + a_0}{s^m + b_{m-1}s^{m-1} + \cdots + b_1 s + b_0} = \frac{a_n \prod_{i=1}^{n}(s-z_i)}{\prod_{i=1}^{m}(s-p_i)}$
  - $m \geq n$
  - a_i and b_i are real for all i.
  - All $b_i's$ are positive (stability)

Continuous-Time Filters

- If the signal is sinusoidal with frequency ω , Replace s with $j\omega$
- $H(s) \rightarrow H(j\omega)$
- $H(j\omega) = \ |H(j\omega)|\, e^{j\phi(\omega)}$
- In most cases, we represent the magnitude as :
  - $A(\omega) = 20\log(|H(j\omega)|)$ (dB) [Even Function : $A(\omega) = A(-\omega)$]
  - $\phi(\omega) = \arg[H(j\omega)]$ (degree) [Odd function: $\phi(\omega) = -\phi(-\omega)$]
- Group delay: Sometimes it is useful to look at the group delay of a filter $\tau_G(\omega) = -\frac{d\phi(\omega)}{d\omega}$ (sec.)
- Units of group delay is time. Group delay represents the time delay that each frequency component will experience due to the filter characteristics.

Pole-Zero Locations





- $H(s) = \frac{N(s)}{D(s)} = \frac{a_n \prod_{i=1}^{n}(s-z_i)}{\prod_{i=1}^{m}(s-p_i)}$
- Since all coefficients of N(s) are real, Zeros of H(s) can be real or complex conjugate.
- Similarly for D(s), Poles of H(s) can be real or complex conjugate. For stability purposes, all real part of poles must be negative (< 0).

Stability

- Mathematically, for a system to be stable:
  - $\int_0^{\infty} |h(t)| dt = M < \infty$
  - Only expressions that are allowed: $A\ t^n e^{-\sigma t} \sin(\omega t)$
    - Where σ is a positive → Decaying exponential.
    - Pole must be on the form of $\frac{1}{s+A}$, left-half-plan pole (A is positive).
- What about the impulse response of a right-half plan pole?
  - $h(t) \sim e^t$: Positive exponential → Unstable